On-Off-Keying with Variable Rate for Optical Wireless Communication using ITU-T G.9960

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***Abstract*—In this work, we introduce new on-off keying physical layers for optical wireless communications. On-off keying modulation has a lower peak-to-average power ratio than orthogonal frequency-division multiplexing, thereby increasing the achievable range between transmitter and receiver. It also enables switched-mode power amplifiers for driving the laser, reducing power consumption in battery-driven mobile devices. Here, we propose a dual-mode transceiver architecture that can switch between both modulation schemes. The only difference is that the inverse fast Fourier transform is not performed at the transmitter for on-off keying, but is moved to the receiver after frequency-domain equalization. This is a minor change to the existing signal-processing chain and could be introduced easily in future chipsets, while other functions, like forward error correction, segmentation and selective retransmission remain unchanged. In addition, we introduce a sample-and-hold mechanism that allows consecutive repetition of each on-off keying chip by a factor from 1 to 32 to support rate adaptation under variable channel conditions. We exemplify both ideas using ITU-T Recommendation G.9960 for home networks (which details the physical layer for the G.hn specification), where these minor changes have been applied. In coax mode, nominal clock rates are 50, 100, and 200 MHz in the standard's normal operating mode; for the extended mode, we consider 400, 800, and 1600 MHz. These clock rates and repetition factors enable effective baud rates between 1.5625 MHz and 1.6 GHz. Simulations in additive white Gaussian noise show frame start detection and header decoding probabilities above 99% at signal-to-noise ratios of –24.5 dB and –24 dB, respectively. With signal-to-noise ratios from –22.5 dB to +8.5 dB, payload detection is also possible at clock rates up to 1.6 GHz, following the theoretical 3 dB gain when doubling the rate. The new on-off-keying physical layer supports operation between 1.5 Mbit/s and 1.6 Gbit/s, enabling seamless mobile operation in both non-line-of-sight and line-of-sight conditions.**

***Index Terms*—On-Off Keying, Physical Layer, Home Network, LiFi, Optical Wireless Communication, Wireless Communication, OFDM, Visible Light Communication.**

I. Introduction

Optical wireless communication (OWC) is a promising solution for applications ranging from intra-satellite communications to indoor mobile communications [1]. It offers unique advantages, including unlicensed spectrum with bandwidth orders of magnitude higher than radio frequency (RF), higher potential for spatial reuse, low-cost components, and intrinsic physical layer security, since communication is possible only within the light cone. Orthogonal frequency-division multiplexing (OFDM) is a popular modulation format for OWC due to high spectral efficiency and the ability to adapt to time- and frequency-selective channels via low-complexity frequency-domain equalization and adaptive bit-loading. However, OFDM has a high peak-to-average power ratio (PAPR), requiring optical front-ends (OFEs) with high linearity and power consumption, which increases cost. In addition, optical OFDM needs a direct current (DC) bias to ensure a non-negative signal. Clipping at zero is typically chosen so that thermal noise and clipping-induced interference are comparable; decreasing OFDM power efficiency. G.9960 [2] is an ITU-T recommendation for home networking at data rates up to 2 Gbit/s. It specifies the architecture and physical layers (PHYs) for several media, including powerline, twisted pair, coax, and plastic optical fiber. In Amendment 2 (03/25), ITU-T adopted two on-off keying (OOK) modulated PHYs for optical media. OOK maximizes optical power utilization for data transmission and enables energy-efficient switched-mode drivers for LEDs and lasers. OWC channel frequency-selectiveness and time-variancy need to be tackled by efficient equalization and link adaptation. Following the G.996x philosophy of supporting multiple media, a signal-processing chain should share as many functional components as possible across media types. In [2], we proposed applying a well-known digital subscriber line (DSL) principle: an OFDM PHY can be converted into a single-carrier PHY with frequency-domain equalization (FDE) by shifting the inverse fast Fourier transform (IFFT) from transmitter to receiver, immediately after FDE [3]. We also proposed a sample-and-hold factor (SHF) that sets how often an OOK chip is repeated, enabling fine-grained bandwidth and data-rate adaptation. Together, these ideas allow reuse of OFDM processing blocks over optical media. In this paper, we evaluate both OOK PHYs and illustrate their benefits. The paper is organized as follows: the OOK PHYs are introduced in section II, the simulation

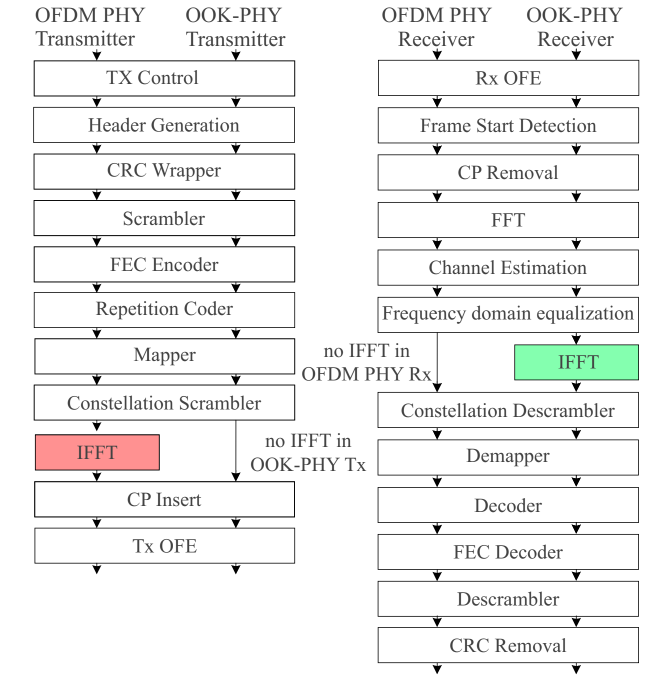

Fig. 1: Functional schemes of the transmitter and receiver signal processing chains in OFDM and OOK-PHY.

setup is described in section III, results are given in section IV, and conclusions are drawn in section V.

II. The On-Off Keying Physical Layer in G.9960

Gigabit Home Networking (G.hn) is a specification for wired and wireless home networking, and ITU-T Recommendation G.9960 specifies its physical layers and architecture. Amendment 2 to G.9960, approved in March 2025, added OOK-PHY and OOK-HCH-PHY, where HCH stands for “High Capacity Header”. The OOK Rate (OOKR) values specified for the basic OOK-PHY are 50, 100 and 200 MHz [2]. A new feature in Amd. 2 is the K-OOKR value set by the MAC layer, enabling higher OOK rates when supported by devices and channel conditions. The SHF feature has also been added to reduce the effective OOK rate. This is achieved by repeating each OOK chip SHF times. SHF enables bandwidth adaptation for varying channels and can range from 1 to 32, allowing a minimum effective rate of 1.5625 MHz. Header transmission always uses the minimum effective rate, i.e. an OOKR of 50 MHz and an SHF of 32. Both PHYs require, by design, minimal modifications in the transmitter and receiver signal processing chains with respect to legacy OFDM-based PHY and HCH-PHY. This is illustrated in Fig. 1. In the OOK-PHY transmitter structure, the IFFT operation is removed, since there is a one-to-one correspondence between logical bits and OOK chips transmitted through the channel. The receiver structure of OOK-PHY also closely follows the OFDM PHY one, with some exceptions. In OOK-PHYs, in fact, the IFFT is applied to the equalized signal to transform it from frequency-domain to time-domain, where the chips of the OOK sequence are restored, enabling further processing steps.

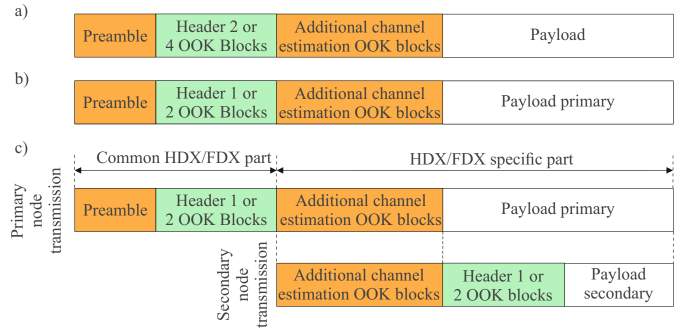

Fig. 2: Format of the OOK-PHY frames. a) OOK-PHY frame. b) OOK-HCH-PHY HDX frame. c) OOK-HCH-PHY FDX frame.

The OOK-PHY frame format, shown in Fig. 2, follows that of pulsed modulation PHY (PM-PHY) in IEEE Std 802.15.13 [4], where the preamble, transmitted at OOKR = 50 MHz and SHF = 1, comprises a first section for automatic gain control, a second for synchronization, and a header channel estimation sequence. For the header, a pseudo-random Gold sequence is used for channel estimation and is transmitted with same OOKR and SHF as the header. The header is sent over two or four 168-bit-long OOK blocks in OOK-PHY, and over one or two OOK blocks in OOK-HCH-PHY. OOK-HCH-PHY, like legacy OFDM HCH-PHY, defines different frame formats for Half Duplex (HDX) and Full Duplex (FDX) modes. The Gold sequence for payload channel estimation is transmitted with same OOKR and SHF as the payload (as specified in the header) and is used for FDE. The number of bits per payload OOK block depends on OOKR. OOK block duration is independent of OOKR, but proportional to SHF.

III. Performance Evaluation

We conducted Monte Carlo simulations in MATLAB to evaluate key performance indicators (KPIs) for OOK-PHYs at different signal-to-noise ratio (SNR) levels. These KPIs are frame synchronization probability (probability that the receiver correctly detects frame start), probability of correct header detection, and probability of correct payload detection. Payload detection probability is derived from average bit error rate after forward error correction (post-FEC BER) at each SNR level, as in [5], [6]. Simulations were run for payload OOKR values from 1.5625 MHz to 1.6 GHz, doubling at each step (for example, 1.5625 MHz, 3.125 MHz, . . .). The receiver sampling rate was set to 3.2 GHz, that is, twice the highest evaluated OOKR. An additive white Gaussian noise channel was used, with constant noise power spectral density across OOKR values. Frame synchronization and header detection probabilities were estimated over 7500 Monte Carlo iterations. For payload detection, 8 Mbit of data were transmitted to compute pre- and post-FEC BER.

IV. Results

In Fig. 3(c), frame start and header detection probabilities are shown for increasing SNR. Frame start and header are

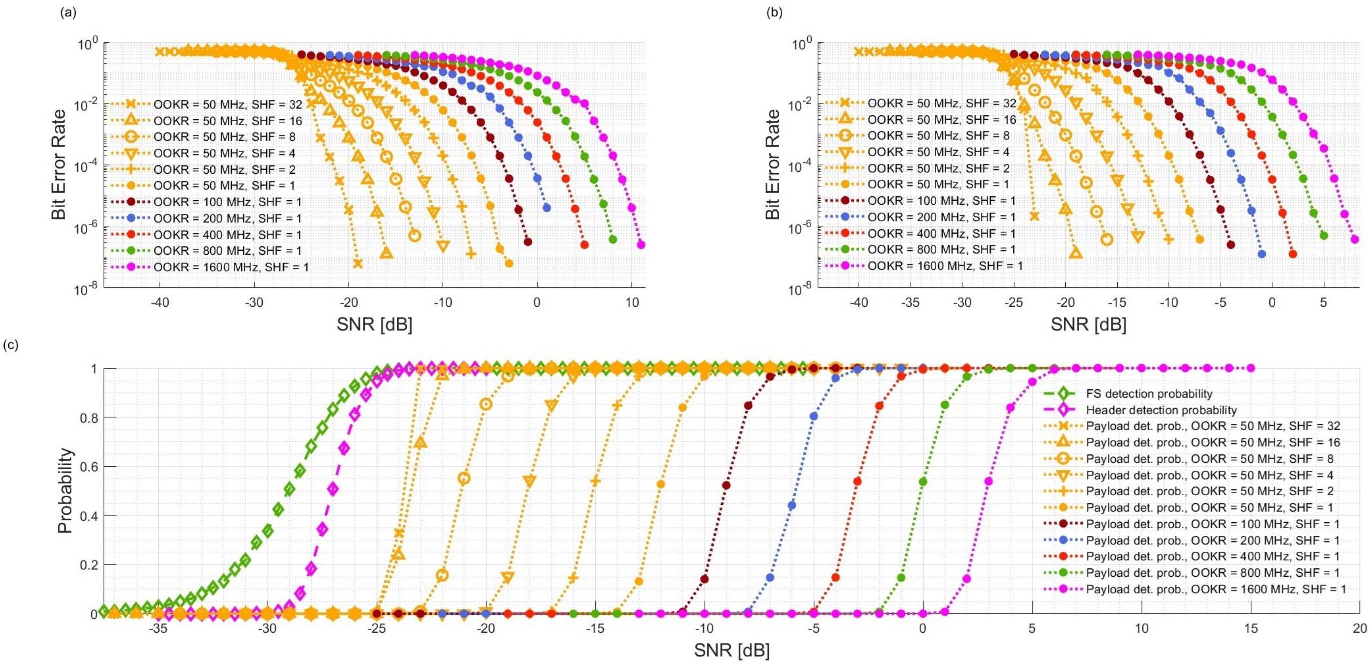

Fig. 3: Performance indicators for OOK-PHY. (a) Payload Pre-FEC BER, computed over 8 Mbit of transmitted data. (b) Payload Post-FEC BER, computed over 8 Mbit of transmitted data. (c) Frame start, header and payload detection probability.

correctly detected with 99% probability at SNR values of -24.5 dB and -24 dB, respectively. Fig. 3(a) and (b) report pre-FEC and post-FEC BER versus SNR for OOKRs between 1.5625 MHz and 1.6 GHz. It can be observed that doubling OOKR, or equivalently halving SHF, improves performance by 3 dB, in line with theoretical expectations. At very low SNR, the separation between curves for successive OOKRs drops below 3 dB, as incorrect frame start or header detection becomes non-negligible and increases average BER (incorrect frame start or header detection is counted as a 50% BER event). From these results, correct payload detection requires SNR values of -22.5, -18.5, -15.5, -12.5, -9.5, -6.5, -3.5, -0.5, 2.5, 5.5, and 8.5 dB for the evaluated OOKR values from 1.5625 MHz to 1.6 GHz, using a sampling frequency of 3.2 GHz. These results demonstrate the viability of the proposed OOK-PHY, supported by the sequential increase of SNR requirements for frame start detection, header decoding, and payload decoding in Fig. 3(c), consistent with the dependency of each step on the previous one.

V. Conclusion and Outlook

This paper presented new features and performance results for the OOK physical layers added in ITU-T G.9960 Amd. 2 (03/25). Both OOK-PHYs reuse most components of the legacy OFDM PHY signal-processing chain. This enables dual-physical-layer transceivers on the same chipset, requiring only the addition of an IFFT block at the receiver; this reduced redundancy increases power efficiency compared to having two independent PHY chips. The new SHF feature enables rate adaptation across three orders of magnitude (1.5625 Mbit/s to 1.6 Gbit/s) and operation across diverse devices and channel conditions. For mobile OWC, devices experience varying SNR depending on their location relative to the access point. Rate adaptation helps in critical scenarios, for example when moving from unobstructed line-of-sight to blockage, where the link is maintained only via diffuse reflections. Free-space optical links should also be robust to severe weather such as fog, dust, and rain. While OOK increases reach compared to OFDM [7], rate adaptation using the SHF can further enhance link availability. Passive optical networks exhibit 10–20 dB signal-to-noise ratio variations at optical network units in deployed fiber-to-the-home scenarios. Maximizing the rate minimizes the duration of the time slot assigned to each user, enabling higher capacity for other users in multi-user applications.

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